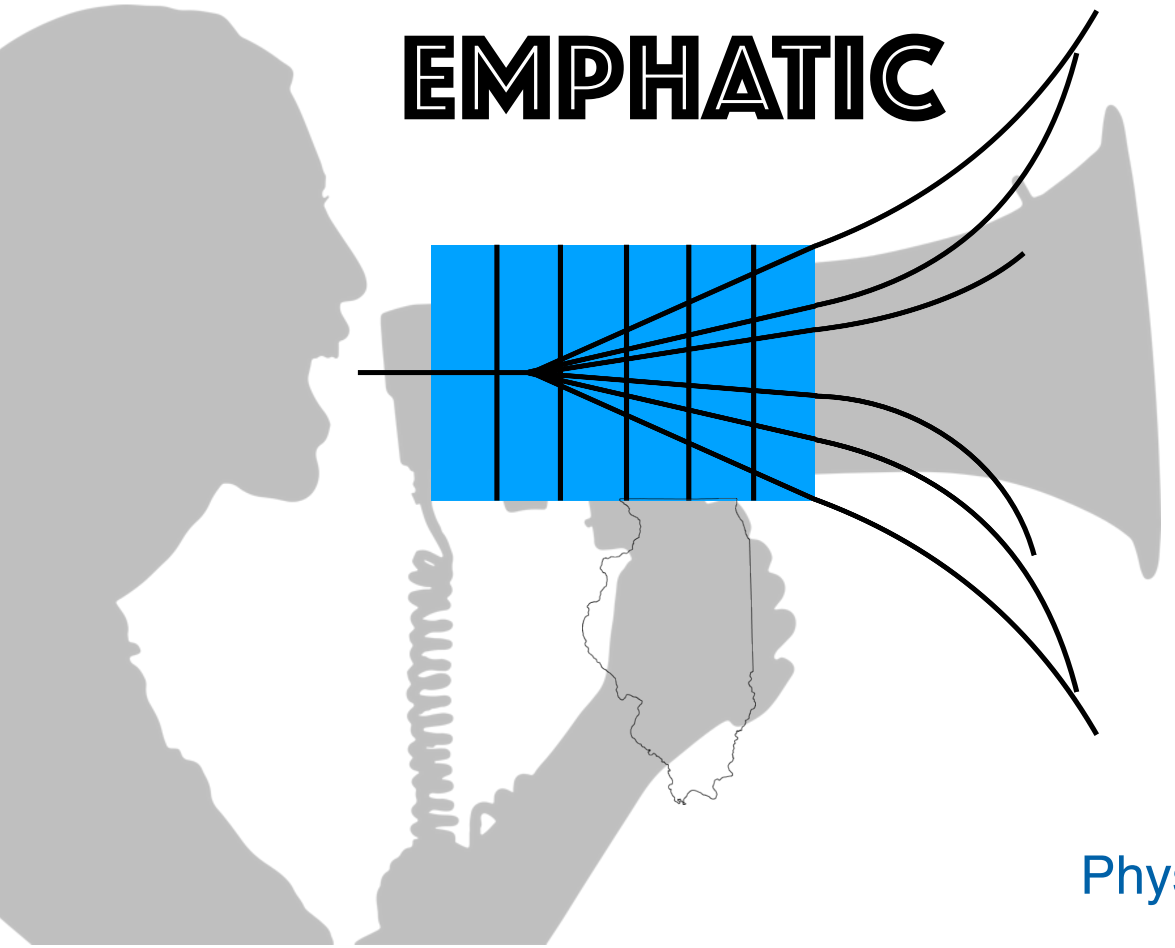
FERMILAB-SLIDES-19-020-ND



A new hadron production experiment for improved neutrino flux predictions

Jonathan Paley
On Behalf of the
EMPHATIC Collaboration

Physics Opportunities in the Near DUNE Detector Hall
Tuesday, Dec. 4, 2018

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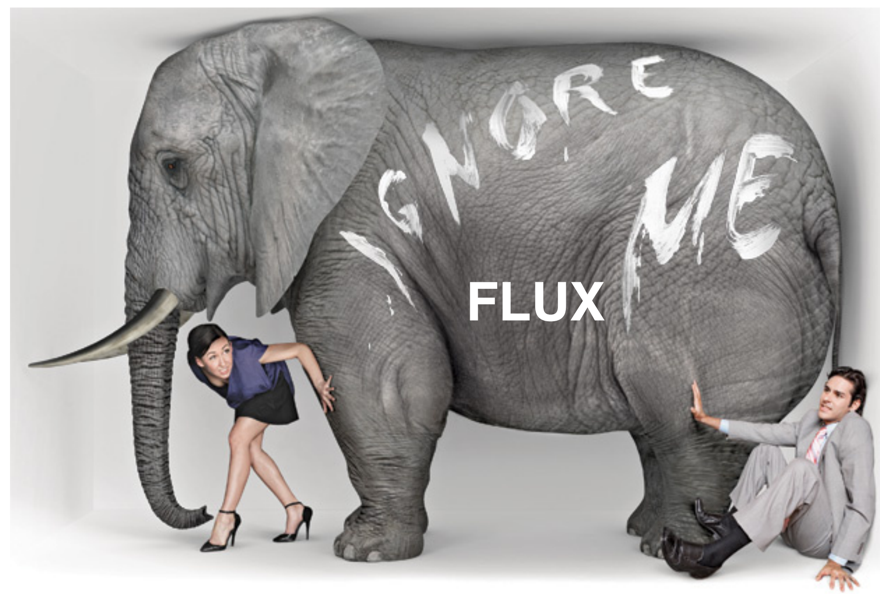
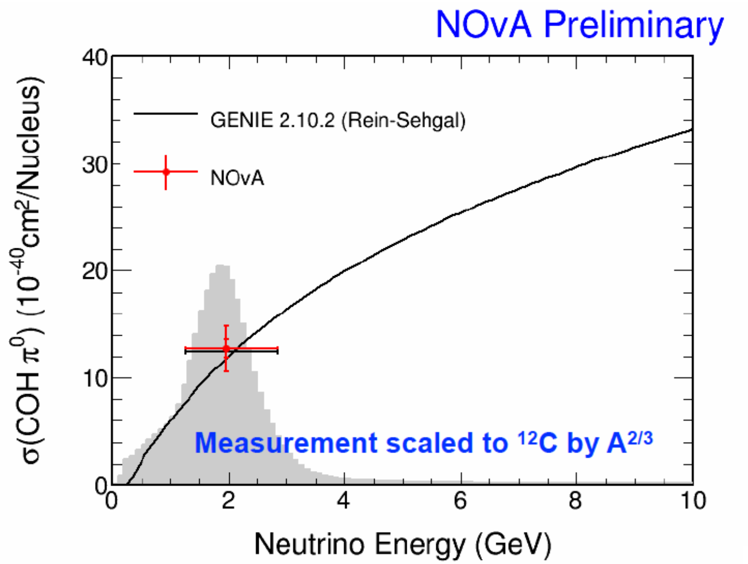
So you want to do a physics analysis with the DUNE ND Data?

- Want precision cross section measurements?
- Some other kind of BSM constraint?

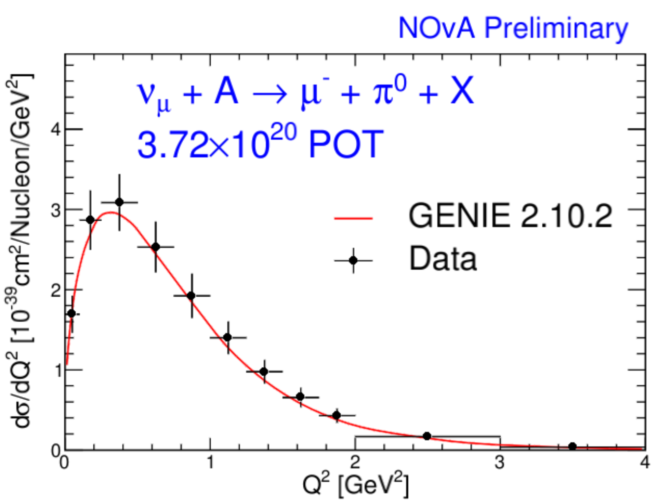
Flux uncertainties are often a limiting systematic!

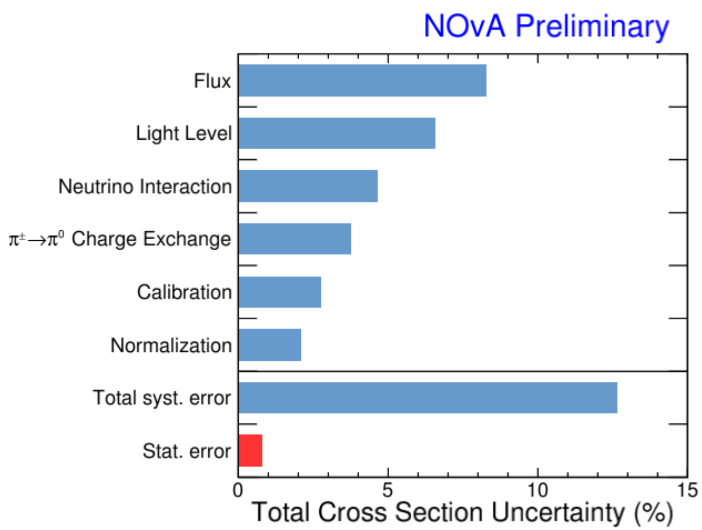


Examples from NOvA - ND Cross Sections

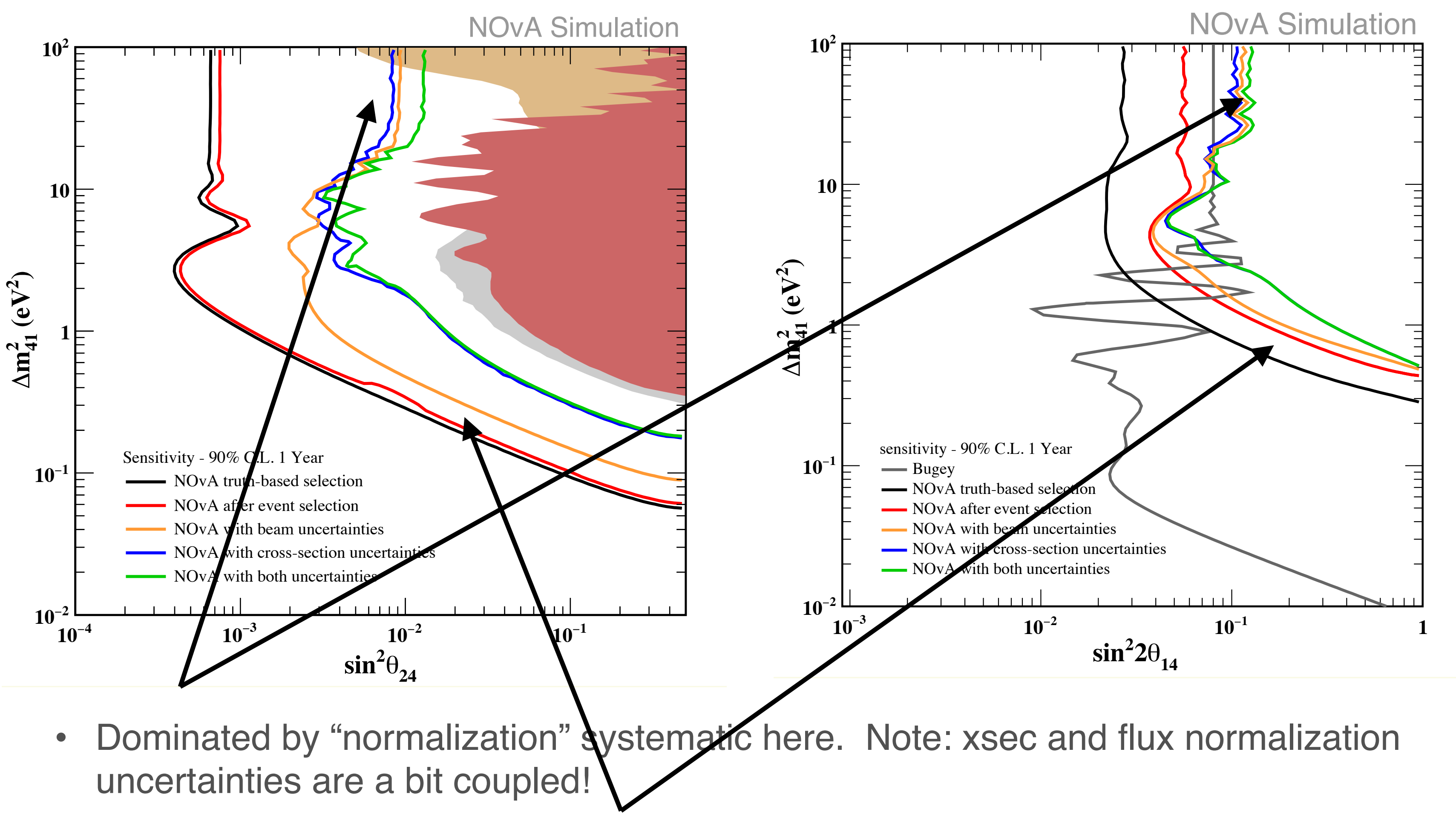


Source	δ(%)
Calorimetric Energy Scale	3.4
Background Modeling	10.0
Control Sample Selection	2.9
EM Shower Modeling	1.1
Coherent Modeling	3.7
Rock Event	2.4
Alignment	2.0
Flux	9.4
Total Systematics	15.3
Signal Sample Statistics	5.3
Control Sample Statistics	4.1
Total Uncertainty	16.7



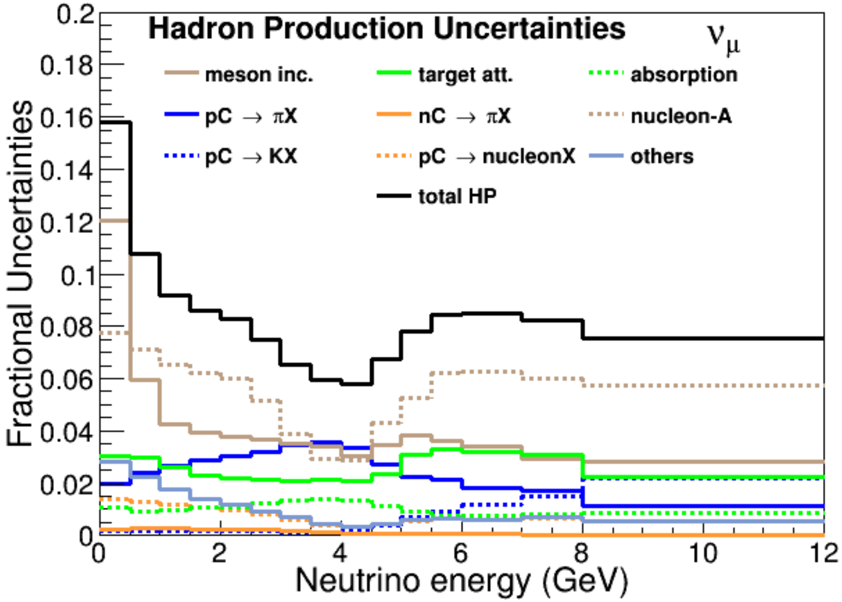


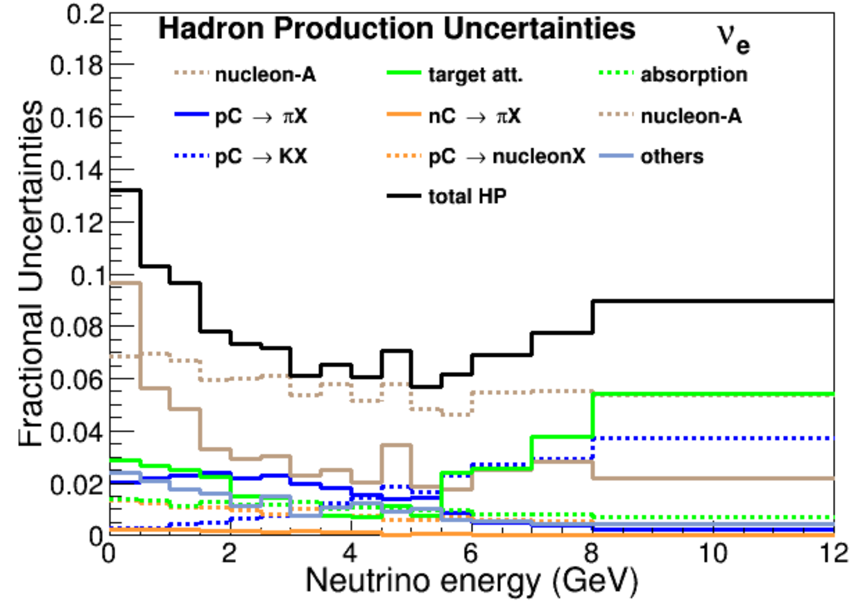
Examples from NOvA - ND Only Sterile Search



- Dominated by “normalization” systematic here. Note: xsec and flux normalization uncertainties are a bit coupled!
- Dominated by “shape” systematics. Note again that xsec “shape” systematics have significant contributions from flux uncertainties.

DUNE Flux Uncertainties



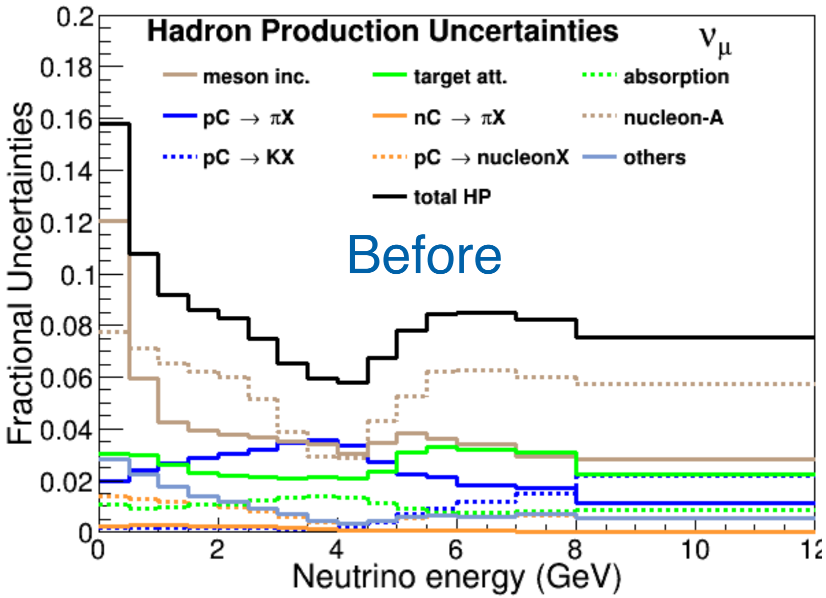


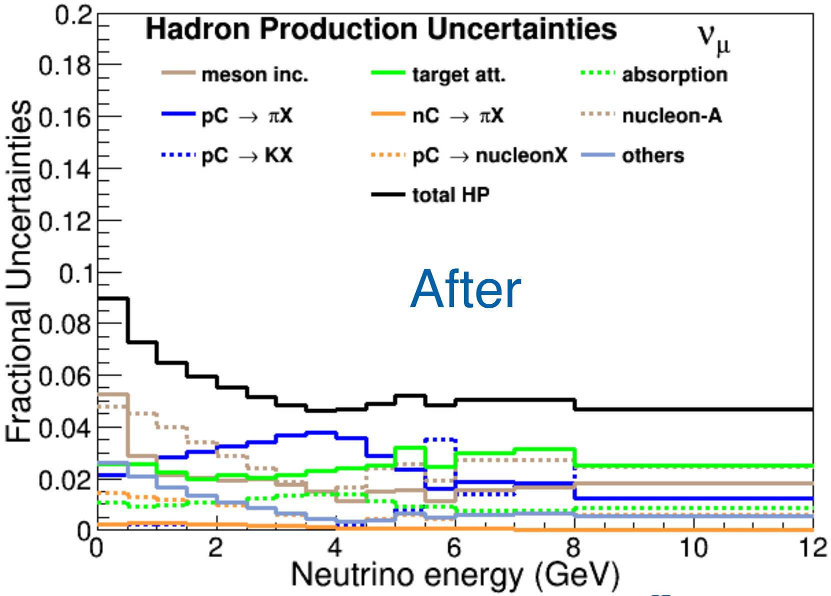
plots from Leo Aliaga

- Dominant NOvA flux uncertainties come from 40% xsec uncertainties on secondary protons interacting in non-carbon materials in the target and horns.
- Lack of proton and pion scattering data at lower beam energies that NA61 cannot obtain.
- ~10% discrepancies observed between thin- and thick-target hadron production measurements applied to NuMI and T2K beams. Both use NA49/61 thin-target measurements. Independent measurements would be useful.

DUNE Flux Uncertainties - Can we do better?

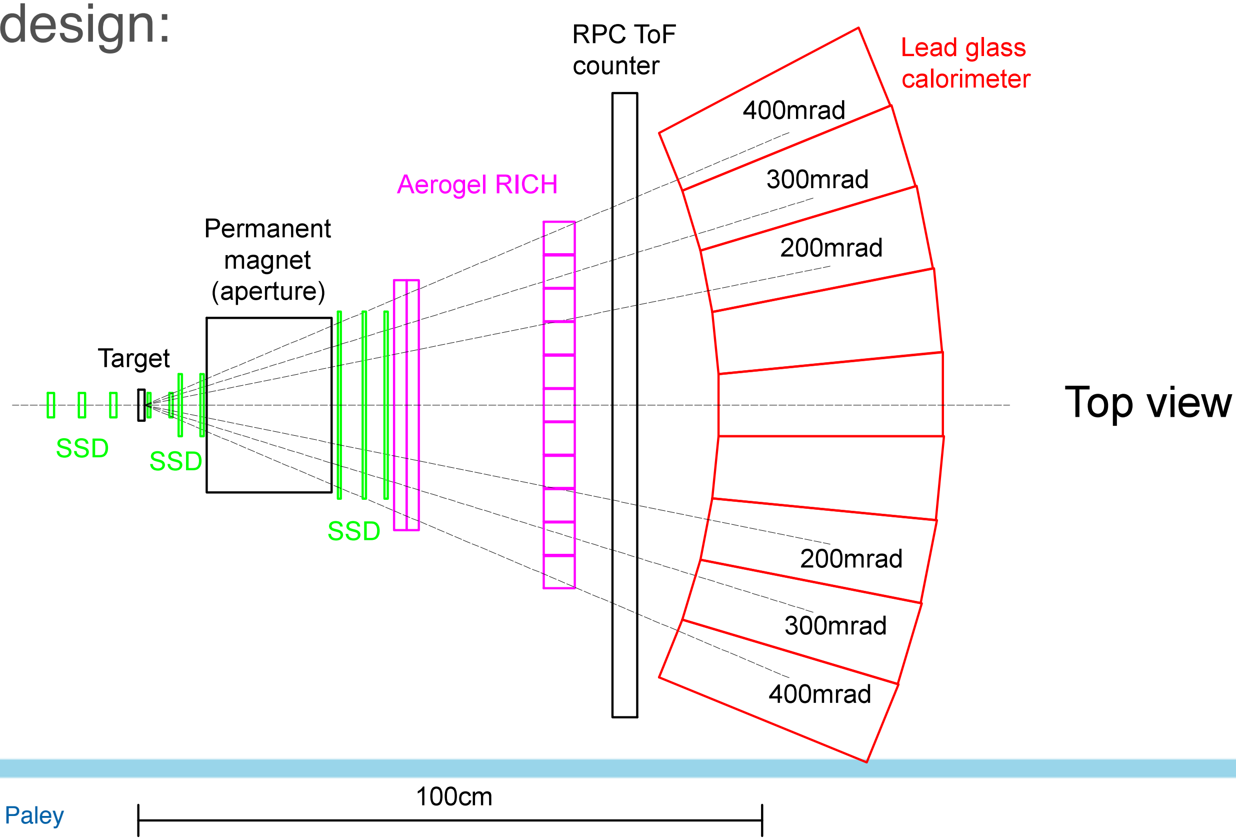
- Reasonable assumptions:
  - Inelastic cross sections:
    - No improvement for pions (5%)
    - 10% uncertainty for kaons (currently 60-90% for p<4 GeV/c, 12% for p>4 GeV/c)
  - 10% on p + C[Fe,Al] —> p + X (down from 40%)
  - 10% on π[K] + C[Fe,Al] —> $\pi^{\pm}$ + X (down from 40%)
  - 20% on π[K] + C[Fe,Al] —> $K^{\pm}$ + X (down from 40%)





EMPHATIC

- **E**xperiment to **M**easure the **P**roduction of **H**adrons **A**t a **T**est beam **I**n **C**hicagoland
  - Uses the FNAL Test Beam Facility (FTBF), either MTest or MCenter
  - Table-top size experiment, focused on hadron production measurements with $p_{beam} < 15$ GeV/c, but will also measure 120 GeV/c p+C.
- Ultimate design:



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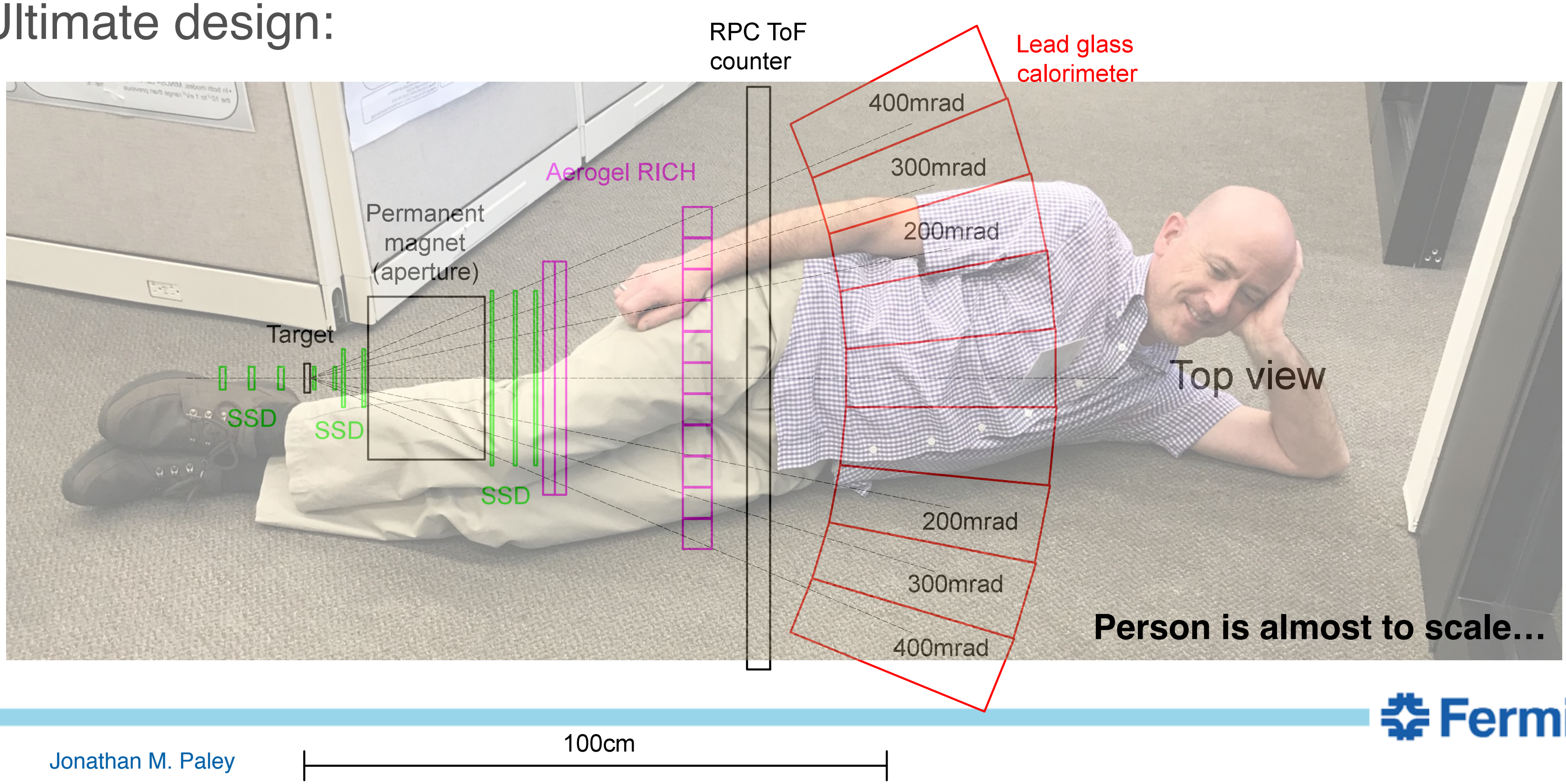

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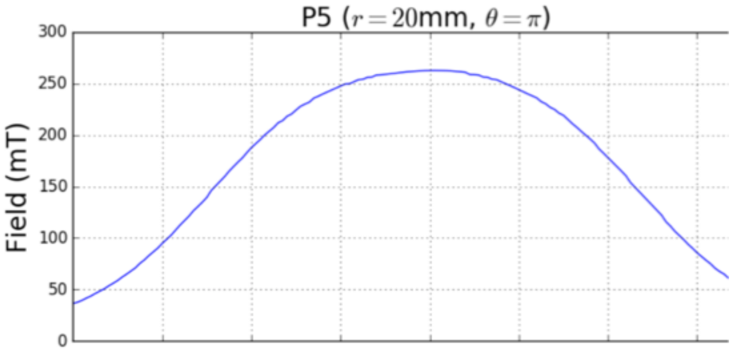
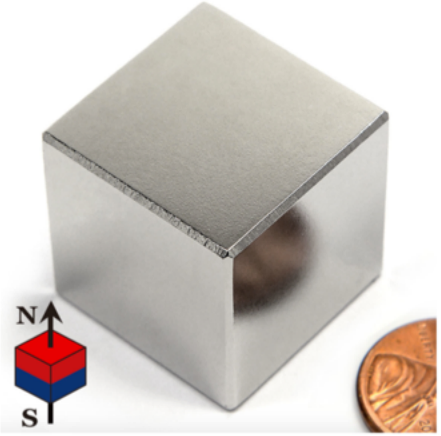
EMPHATIC: Magnet

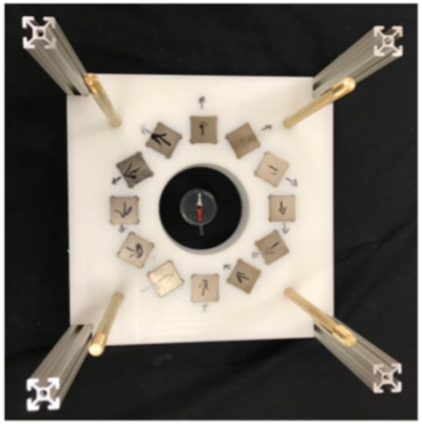
Neodymium permanent magnet
- Internal field: 1.44T
- Low cost: ~$10 for 1-inch cube

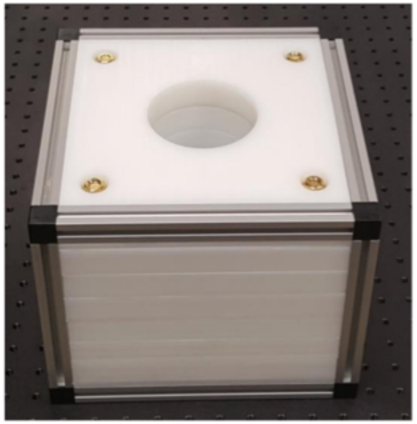
Halbach array build by M. Lang
- 10cm bore radius and B=0.25T



~$1000 magnet

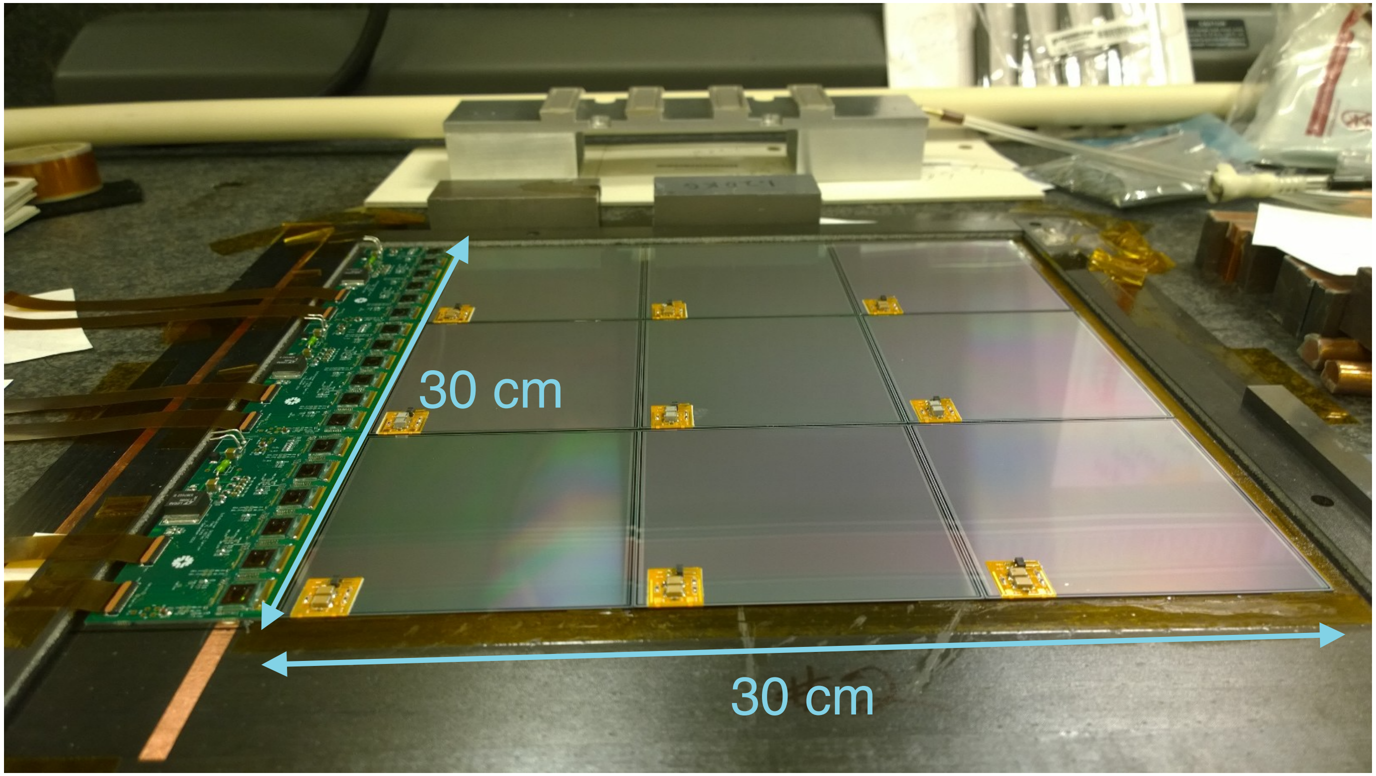






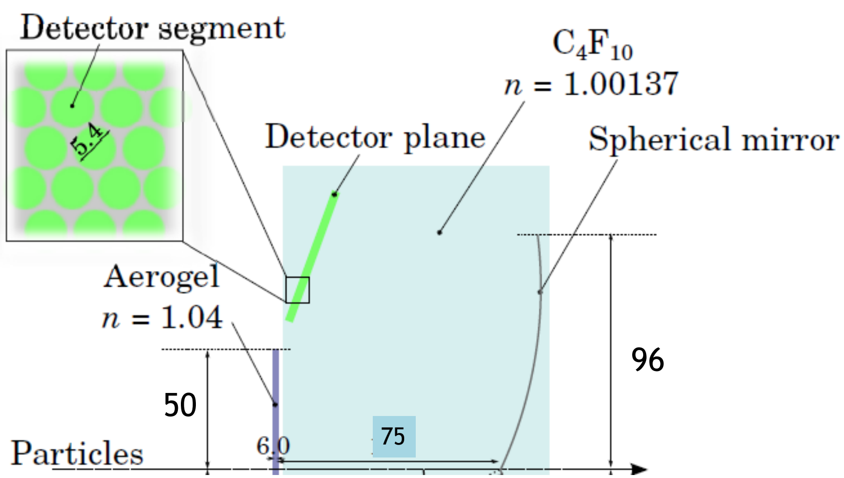
- **Need to scale up bore radius by ~3x**

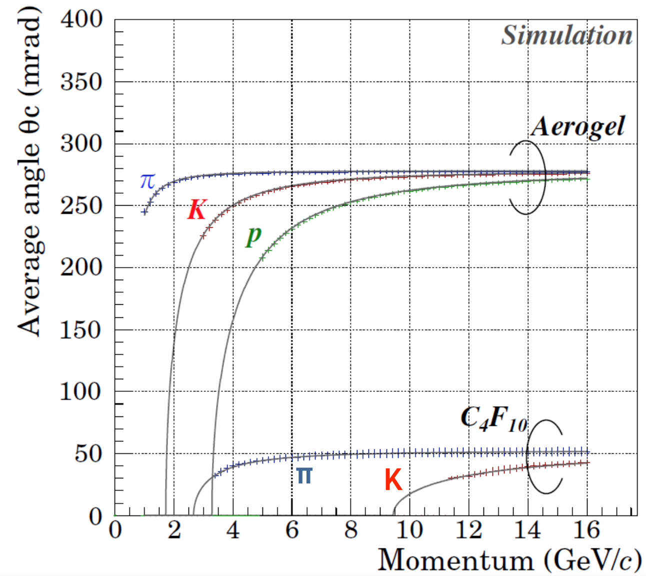
EMPHATIC: Si Strip Detectors



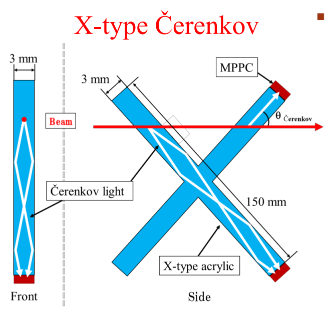
- Large-area SiSDs available from Fermilab SiDet. Existing DAQ system. Resolution good enough for downstream tracking.
- Upstream tracking to be done by existing SiSDs at the FTBF.

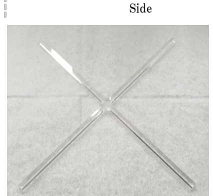
EMPHATIC: PID Detectors (from J-PARC E50)





X-type Čerenkov counter



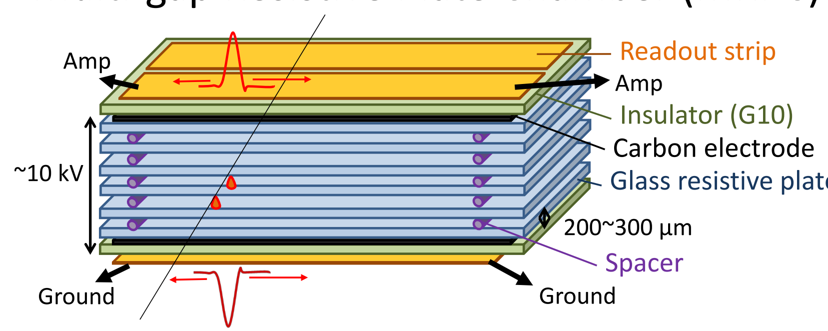


- Developing Čerenkov timing counter
  - Čerenkov lights emit in an extremely short time.
    - ✓Reduce the time spread of photons reaching to the optical sensor
    - ✓Having a fast timing response
    - ✓It has the advantage to measure the better time resolution.
  - Use "Cross shape" acrylic, called X-type, which is cut from an acrylic board
    - ✓In order to cancel position dependences of the time resolution in the Čerenkov radiator
  - The Čerenkov counter is made up of X-type acrylic and MPPC with a shaping amplifier circuit.

It is the first time to use the Čerenkov detector for a timing counter with the X-type acrylic.

Physics with General Purpose Spectrometer in the High-momentum Beam Line 2018/8/28 4

Multi-gap Resistive Plate Chamber (MRPC)

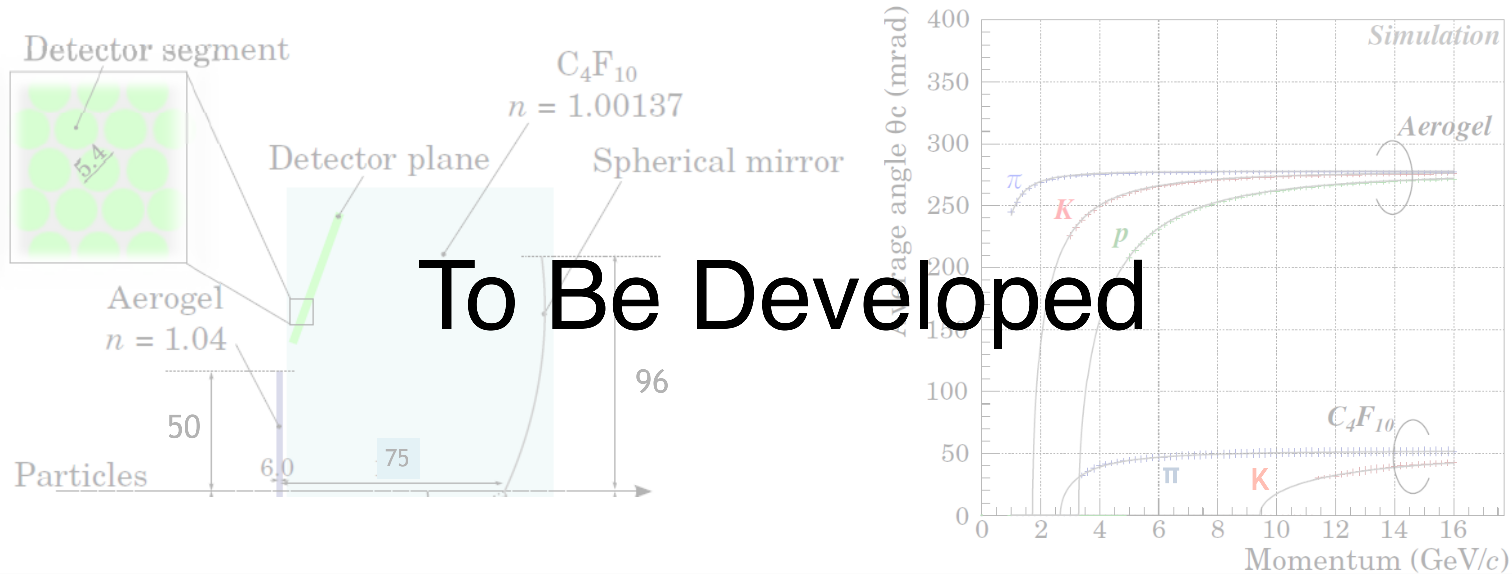


- Resistive Plate -> Avoid discharge
- Smaller gap -> Better time resolution
- Multi gap -> Higher efficiency, better time resolution

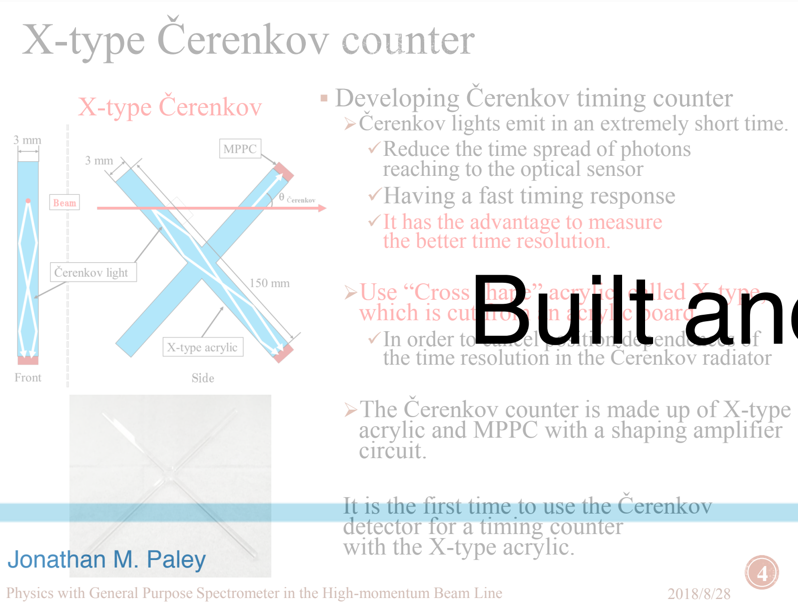
- Can be used under magnetic field
- ~60 ps high time resolution in large area
- Low cost

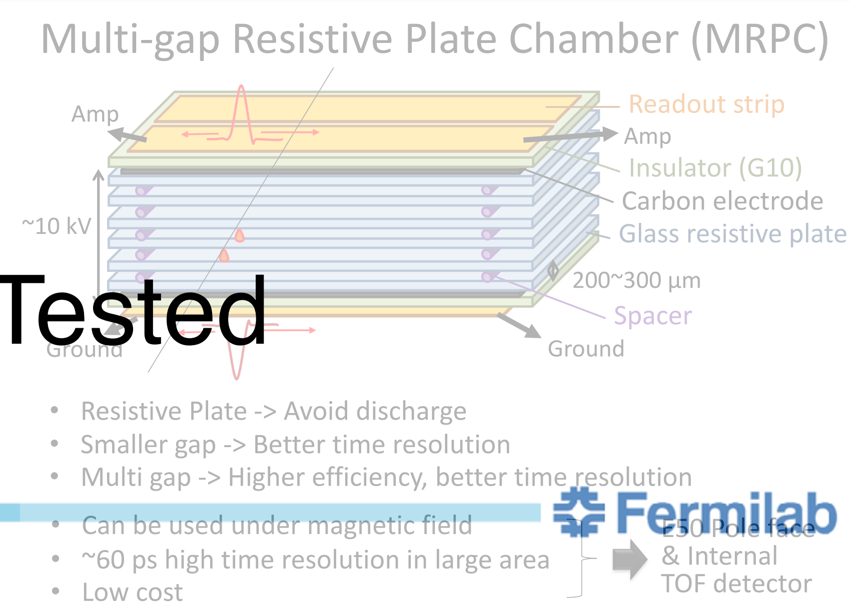
} ➡ E50 Pole face & Internal TOF detector

EMPHATIC: PID Detectors (from E50)



To Be Developed

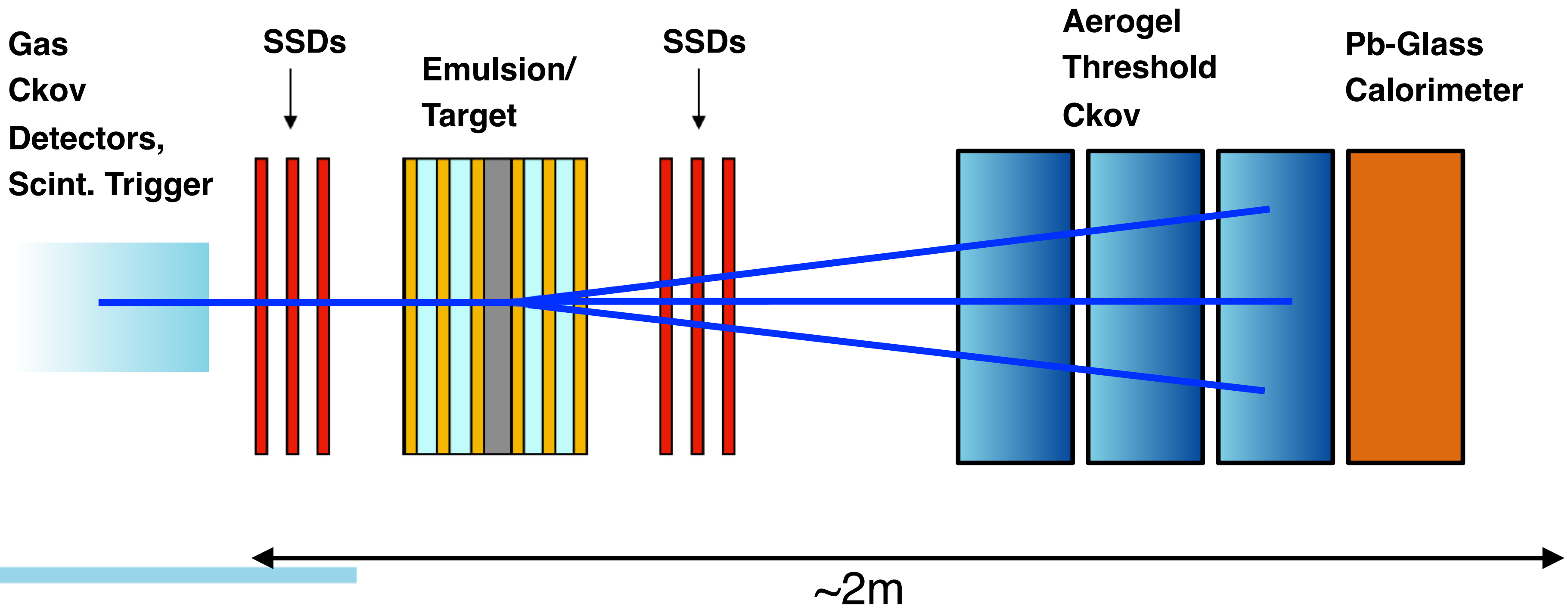




Built and Tested

EMPHATIC: Initial beam test from Jan. 10-23, 2018

- Proof-of-principle/engineering run enabled primarily by 2017 US-Japan funds
  - Japan: aerogel detectors, emulsion films and associated equipment, travel
  - US: emulsion handling facility at Fermilab
  - Critical DAQ, motion table and manpower contributions from TRIUMF

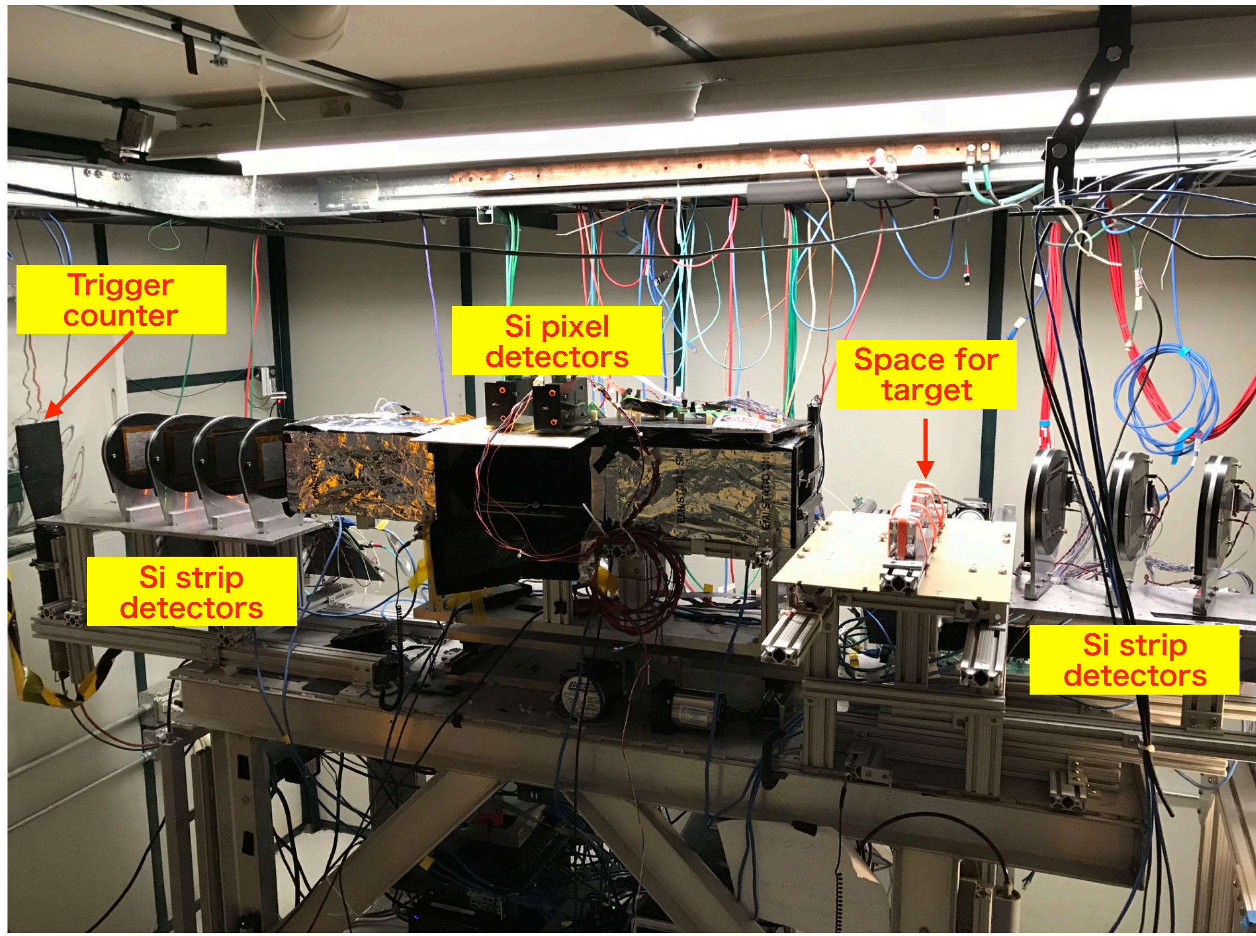


EMPHATIC: Initial beam test from Jan. 10-23, 2018

- Two setups in this run: one with emulsion bricks, another with thin targets

- In each case, we used the existing:
  - SSDs for tracking upstream and downstream of the targets
  - Aerogel Ckovs and Pb-glass calorimeter downstream
  - Two differential gas Ckov detectors upstream to tag the beam (1 w/ two mirrors)

MT6.1-A



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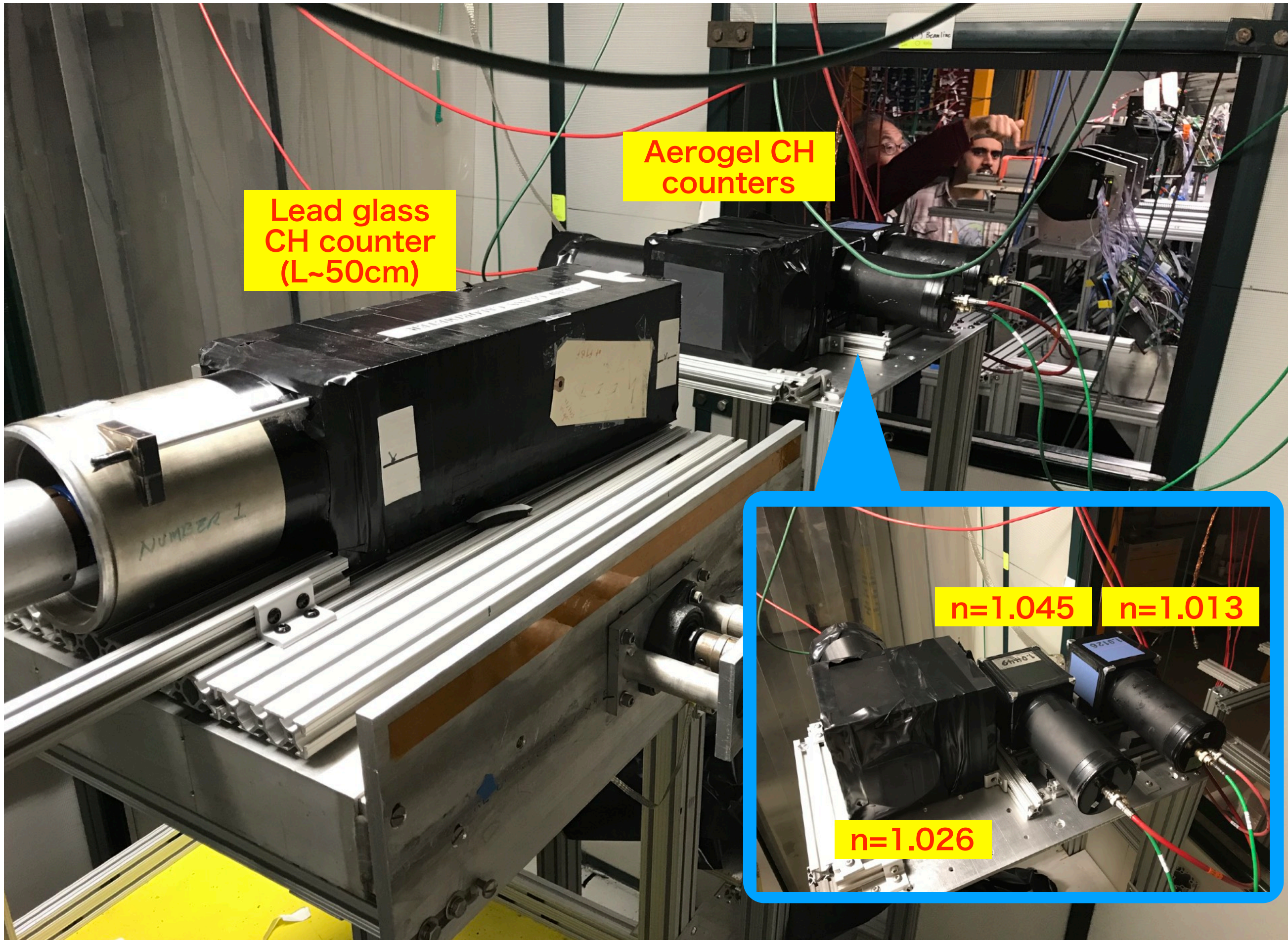
MT6.1-B



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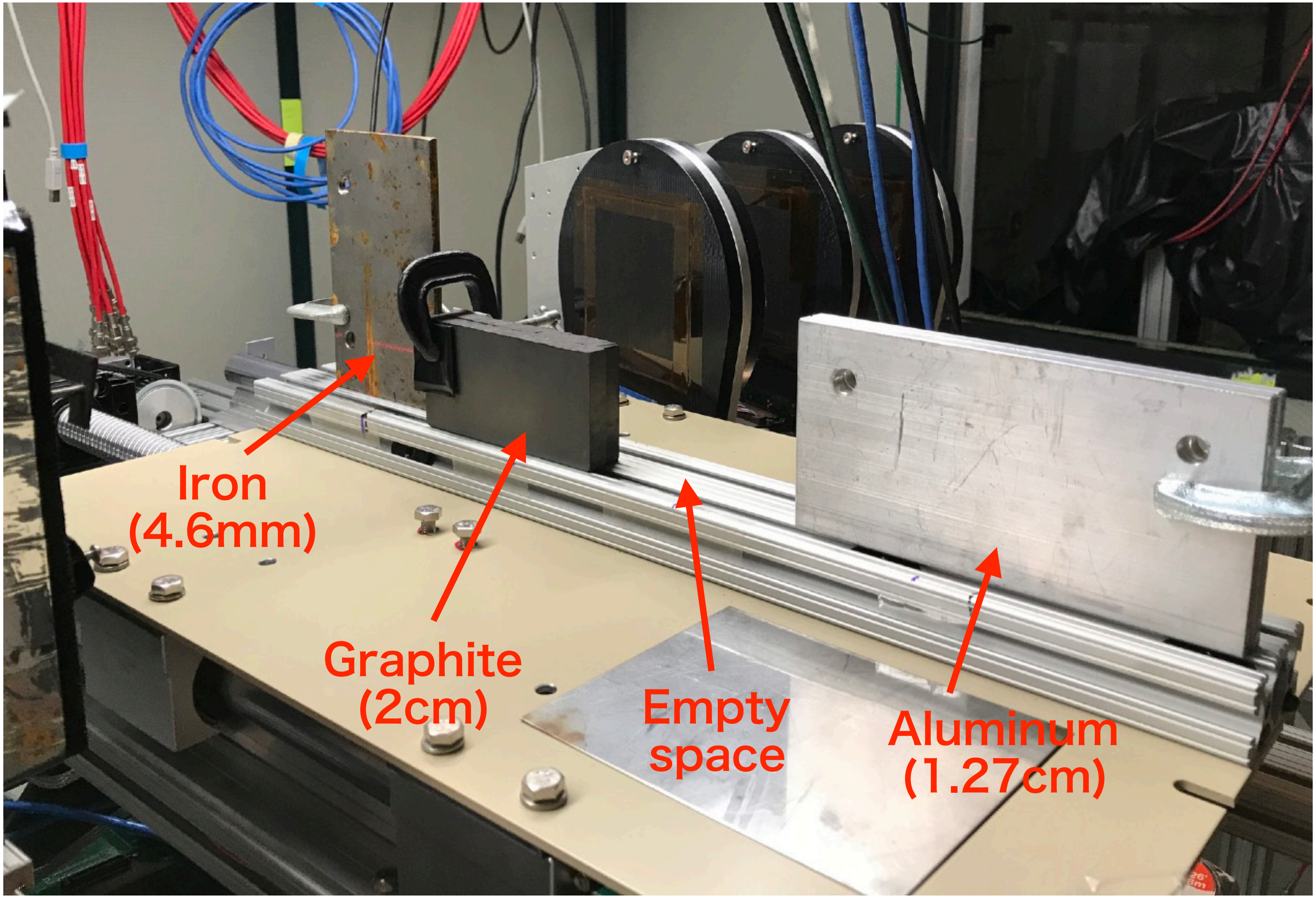
EMPHATIC: Thin-target data w/ silicon tracking only



Fermilab

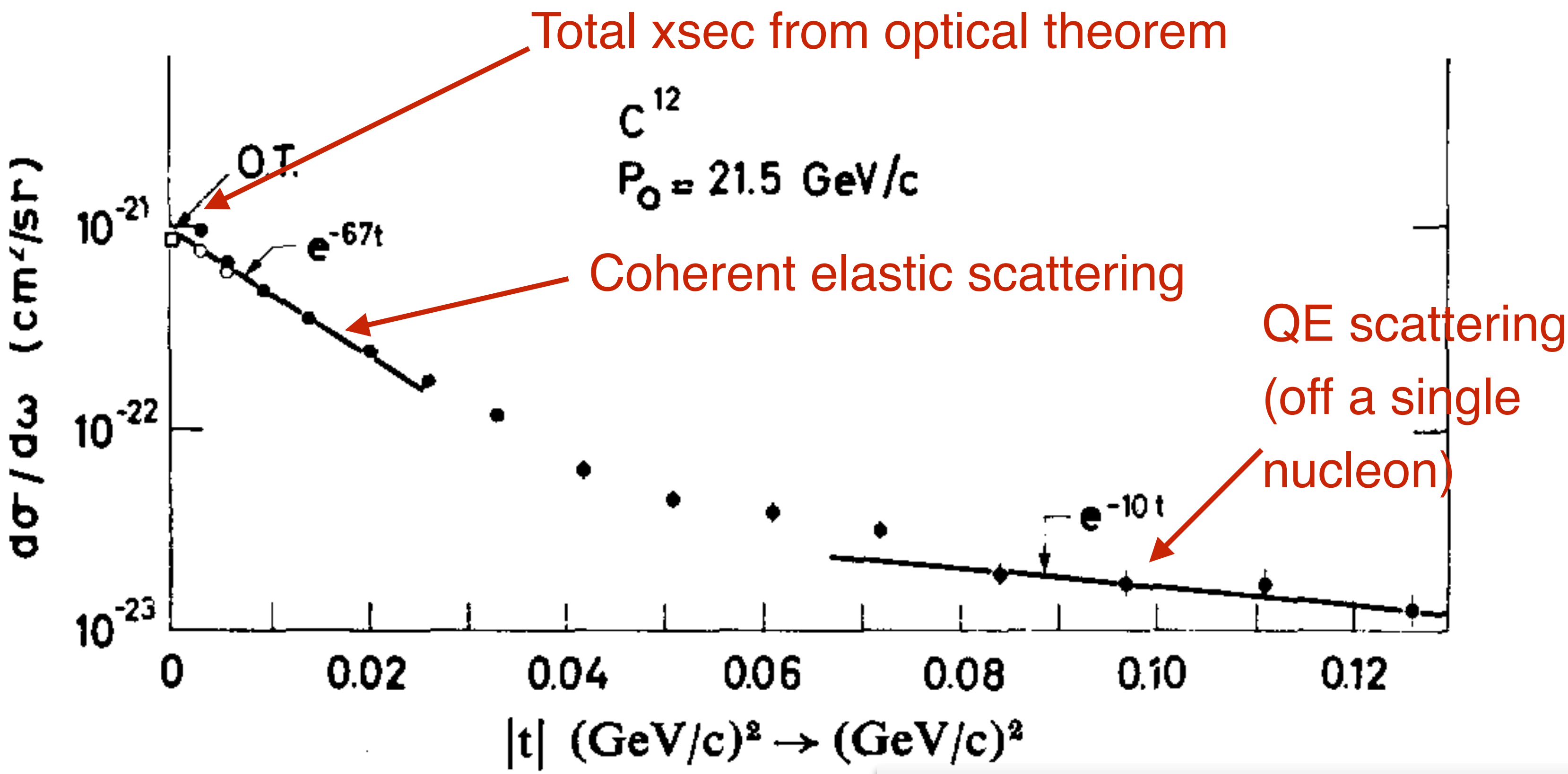
EMPHATIC: Thin-target data w/ silicon tracking only

Number of min. bias triggers

	Graphite	Aluminum	Iron	Empty
120 GeV	1.63M	0	0	1.21M
30 GeV/c	3.42M	976k	1.01M	2.56M
-30 GeV/c	313k	308k	128k	312k
20 GeV/c	1.76M	1.76M	1.72M	1.61M
10 GeV/c	1.18M	1.11M	967k	1.17M
2 GeV	105k	105k	183k	108k

Note: min. bias trigger efficiency is 100%

EMPHATIC: Thin-target data w/ silicon tracking only



G. Bellettini et al., Nucl. Phys. 79, 609 (1966)

$$|t| \simeq p_{beam}^2 \theta_{scatt}^2$$

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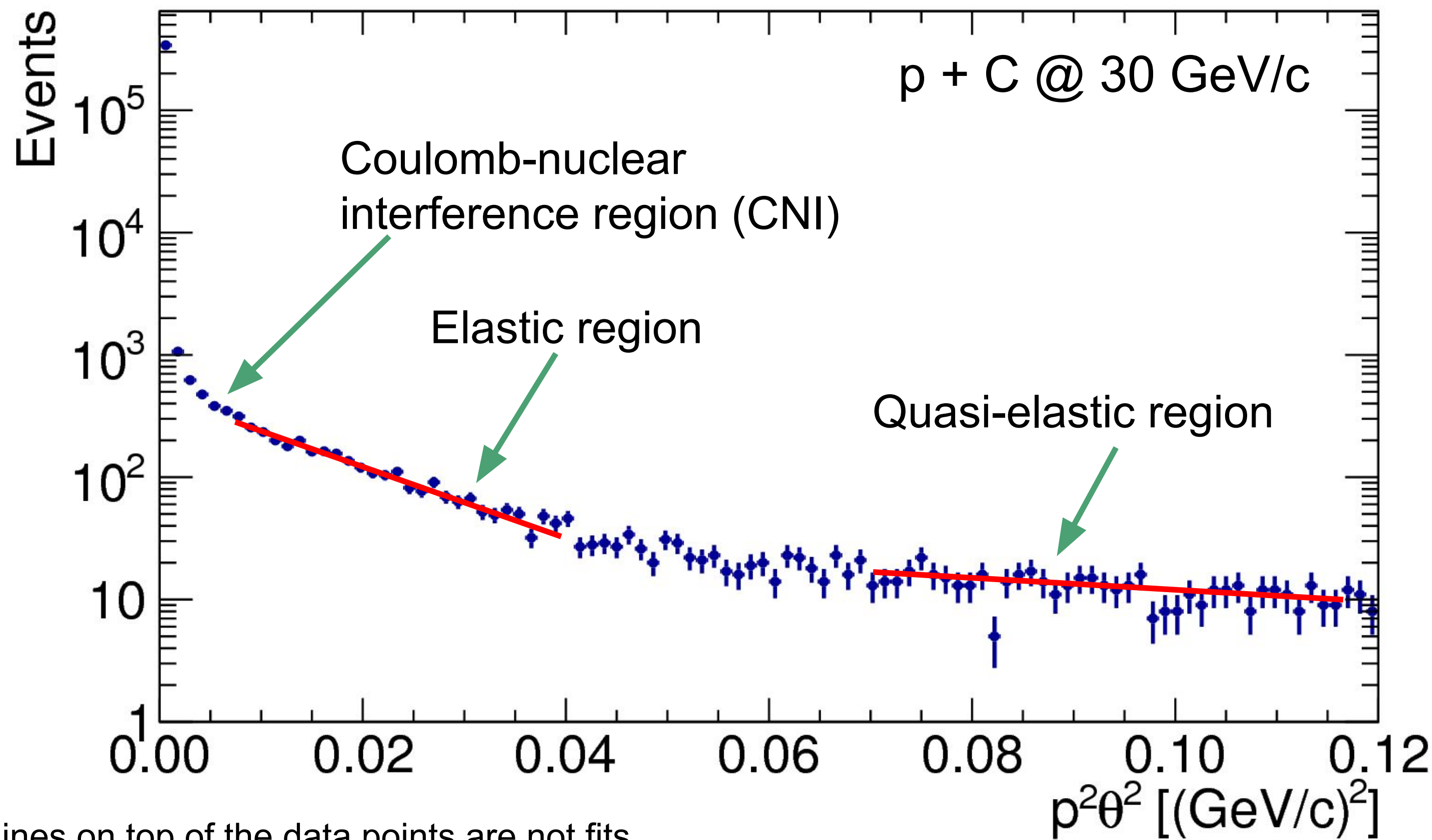
EMPHATIC: Thin-target data w/ silicon tracking only

4-momentum transfer (raw data)

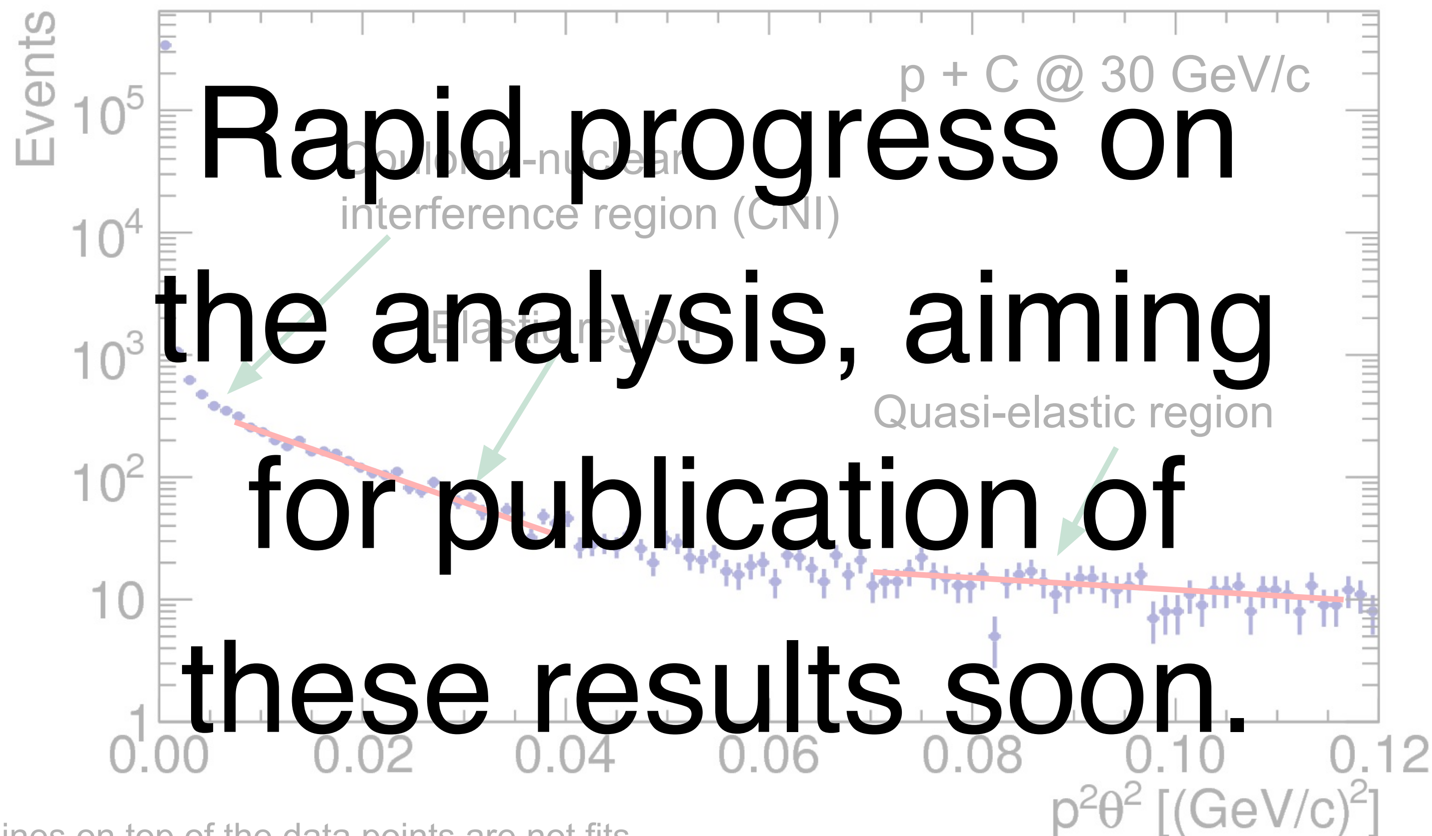


*Lines on top of the data points are not fits

Data are being analyzed, systematics under assessment, but most look to be <5%.

EMPHATIC: Thin-target data w/ silicon tracking only

4-momentum transfer (raw data)



Rapid progress on the analysis, aiming for publication of these results soon.

*Lines on top of the data points are not fits

Data are being analyzed, systematics under assessment, but most look to be <5%.

Summary

- New hadron production data are needed if we want to reduce our neutrino flux uncertainty.
- EMPHATIC offers a cost-effective approach to reducing the hadron production uncertainties by at least a factor of 2.
- We have developed an initial design of the spectrometer, run plans for 2019-21, and are putting together a proposal (should be on arXiv very soon).
- Hardware contributions from Fermilab, Canada and Japan. Possibilities for new institutions: VME-based electronics, DAQ development, people power.
- Useful data collected during an engineering run in January 2018, analysis is progressing rapidly. Aiming for publication of results soon.
- We will collect a huge amount of data in a relatively short amount of time… we need more NuMI/LBNF stakeholder involvement.
- Lots of room for new institutions to get involved!


Come join the fun!

BACKUP